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# A COMPARISON OF METHODS USED TO ESTIMATE BODY DENSITY

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A COMPARISON OF METHODS USED TO ESTIMATE BODY DENSITY" submitted by NADINE PATRICIA MOYER in partial fulfilment of the requirements for the degree of Master of Science.

# ABSTRACT

The reliability of two different makes of skinfold calipers, the Harpenden and the Lange, was tested on a group of physical education students. The reliabilities reported were almost identical.

The accuracy of skinfold regression formulas for predicting density of the human body was also tested. The formulas of Young et al (57) and Sloan et al (49) did give an accurate estimate, but that of Katch and Michael (35) reported a non-significant correlation at the .05 level.

Different techniques of hydrostatic weighing were examined and reliabilities were reported for each method. The inspiration technique using a measured residual volume gave the highest reliability.

The residual volume was estimated and measured directly to determine if there would be a significant difference in body density between these two methods. However, when the mean of the scores was taken there was no significant difference at the .05 level.

The body density estimate, obtained by hydrostatic weighing was used in three formulas, which had been developed by previous researchers, to estimate the percentage body fat. At the .05 level of significance there was no difference among the three estimates of percentage body fat.

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# CHAPTER I

# STATEMENT OF THE PROBLEM

## Introduction

There is an increasing need for estimating total body fatness among undernourished, ill and obese individuals other than by complicated techniques such as hydrostatic weighing, hydrometry, body potassium, somatotyping, gas absorption or ultrasonic methods. These methods are efficient in laboratory and hospital situations, but are generally too involved and expensive for field studies and general medical practice. As a result of this, the use of skinfold measurements as a predictor of body specific gravity is becoming progressively more important.

The calipers used to measure skinfolds are light, mobile and easy to use, giving them an obvious advantage over the heavy equipment needed for other techniques. It remains for them to be accurate and uniform as well. Since skinfold readings are dependent on the characteristics of the caliper involved, it remains that calipers must have a basically similar spring pressure and jaw surface (25,26) before any

comparison can be made of research studies. Presently, studies carried out with different calipers are being compared to each other with no real proof that the calipers are similar enough to warrant it.

A few researchers have developed regression equations which predict body density from skinfold measures (12,18,35,42,49,57) and many studies have been done testing these equations. Reliabilities reported tend to justify the belief that skinfold measures can be used to predict density with a high degree of accuracy. However very few studies have been done to compare the densities predicted by these different formulas. Three equations in particular, those of Young et al (57), Sloan, Burt and Blyth (49) and Katch and Michael (35) could be compared for similarity as they were developed from sample populations of comparable sex, age, height and weight.

The best estimate of specific gravity (or body density) today is hydrostatic weighing, a process by which the body volume is obtained and used to estimate body density. The principle involves underwater weighing with a simultaneous measurement of respiratory air. It is generally agreed that direct measurement of the residual volume in the lungs will give a significantly better estimation of density than will an estimation of

the residual volume (13,37,49). However the evidence is not so conclusive as to which state of respiration, maximal inhalation or maximal exhalation, will give the more reliable result (13,30,52).

Problem

It was the purpose of this study:

1. To test the reliability of two caliper designs; the Harpenden and the Lange.

2. To compare the body densities obtained from the four different predictive equations of Young et al (57), Sloan et al (49), Katch and Michael (35) and a regression equation developed from this study.

3. To estimate the validity of body density predicted from skinfolds.

4. To estimate the reliability of body density employing two techniques of respiration; maximal inhalation and maximal exhalation.

5. To investigate the difference in body density using measured and predicted residual volumes.

6. To investigate the difference among three formulas in predicting body fat. The formulas used are those of; Brozek (12), Rathbun and Pace (44) and Siri (47).

## Main Hypotheses

The hypotheses state that there is no difference at the .05 level of significance:

1. In skinfold values as measured by the two different calipers.

2. In body density, as predicted by four different formulas.

3. In body density, as predicted by hydrostatic weighing and the best skinfold equation.

4. In reliability of density measurements using the criteria of inhalation and exhalation.

5. In body density values, using predicted and measured residual volumes.

6. In percent body fat as estimated by three different formulas.

## Justification

Before universal acceptance of body composition studies can be assured, there is a need to assess the comparability of skinfold measurements taken with different calipers. It is also important to determine just how specific the outlines of a population must be for an accurate estimation of body density and percent body fat.

Limitations

1. The reliability of the investigator and equipment.

2. The temperature and humidity are not controlled in the lab.

3. The constants used in calculation of body fat from specific gravity and density have been derived from studies on males and may not be applicable to females.

4. The techniques used are only estimates of specific gravity and body density.

Delimitations

1. The sample was limited to a random selection of women enrolled in the Bachelor of Physical Education program at the University of Alberta.

2. The estimates of body density were limited to those obtained by hydrostatic weighing and skinfold measures.

3. Only the formulas developed by Young et al (57), Sloan et al (49), Katch and Michael (35) and a regression equation developed in this study, were used to estimate the specific gravity or density from skinfold measurements.

4. Only the formulas developed by Brozek et al (12), Rathbun-Pace (44), and Siri (47) were used to estimate the percent body fat from measurements of

density.

5. Two skinfold calipers were used; the Harpenden and the Lange.

Definition of Terms

1. Hydrostatic weighing is the method of estimating the specific gravity of a body by the use of the underwater weighing apparatus.

The calculations are based on the formula:

$$D_b = \frac{M_a}{M_a - M_w}$$

where $D_b$ = density of the body

$M_a$ = weight of the subject in air

$M_w$ = weight of the subject in water.

2. Density is the mass of the body per unit volume.

3. Specific gravity is the ratio of the density of the body to the density of water at $4^{\circ}C$.

4. Percent body fat is the percent of total body weight expressed as fat.

5. Subcutaneous fat is the layer of fatty tissue beneath the skin.

6. Skinfold is the thickness of a double layer of skin plus subcutaneous fat.

7. Residual volume is the volume of air (l) remaining in the lungs after forced expiration.

CHAPTER II

# REVIEW OF THE LITERATURE

## Hydrostatic Weighing Technique

Hydrostatic weighing, as an estimate of body density, has been reported to have high reliabilities in test-retest situations (30,36,37). Durnin and Taylor (19) reported a difference of less than ±0.004 units in ninety percent of their cases, while Keys et al (38), using a slightly more elaborate technique, showed an error of less than ±0.003 units in ninety percent of their cases. Behnke and his collegues stated that density could be accurately measured within 0.004 units by hydrostatic weighing, provided a correction was made for air in the lungs (5).

In 1962, Howell, Montcrief and Montford (30) reported different reliabilities with different techniques of underwater weighing. They found a reliability of .92 at maximal inhalation and .87 at maximal exhalation. Welch et al (52) however, stated that the most reliable measurements of body density are made after maximal exhalation. Many researchers have measured body density

using exhalation (19,30,36,43,48,49). A few (13,30) have voiced concern over the fact that anxiety in certain individuals as a result of the submersion, may be enough to inhibit complete exhalation. However, Katch, Michael and Horvath (36) have recently obtained reliabilities between .92 and .99 with this method.

Hydrostatic weighing does not, in itself, measure body density, but rather, gives an estimation of body volume. The volume is divided into the body weight to give an estimation of density. In order to eliminate the effect of variable amounts of air in the lungs, the underwater volume must be corrected for residual air in the lungs and gastro-intestinal tract.

The gastro-intestinal volume averages 115 milliliters or less in normal individuals (3,39). However, a 115 milliliter volume is reported to be insignificant and may be neglected in calculations of body density (29,39,51).

The residual lung volume, however, is a relatively large volume and should theoretically make a significant contribution in the final calculation of body density (37,49,53). The determination of residual volume is time consuming, and involves expensive equipment and elaborate techniques. However attempts to estimate the residual volume from

vital capacity or to use an assumed average for all subjects, are questionable. Low correlations have been reported between residual volume and vital capacity. Hurtado and Boller (31), and Wilmore and Behnke (54) reported correlations of r = .457 and r = .169 between residual volume and vital capacity in college age males. Wilmore (53) reported a correlation of r = .435 for men and r = .165 for women, with only the former reaching significance at the .05 level.

The volume of residual air in the lungs has been found by Keys and Brozek (37) to increase with age (from 20 to 60 years) in healthy men and women. They estimated the standard deviation for a given age and sex to be between 400 milliliters and 600 milliliters, which would give an error of ± four percent in the calculation of percent body fat. Sloan et al (49) estimated an error of ± three percent of weight as fat would be introduced if the residual volume was not determined for every subject in the study.

Wilmore (53) has indicated a close agreement between actual body density and that obtained through an estimated residual volume for overall group means, but a high variation between the two when individual measures are taken into consideration. The subjects were 69 males with an average age of 22 years, and 128 females with an

average age of 21 years.

There is evidence to indicate hydrostatic pressure on the thorax affects the pressure-volume relationships of the lungs and thorax (1,33). It has been shown that the expiratory reserve volume of the lungs and the vital capacity decrease significantly under these conditions, but apparantly there is no effect on the residual volume (16). Consequently, measurement of the respiratory volumes with the subject in the water is recommended (13).

Lately, Katch and Michael have reported an interesting correlation between residual volume and body density of college females (35) although they have trouble explaining it. No others have reported this correlation.

## Skinfold Thickness Technique

The technique of skinfold measurement as a predictor of total body fat is fast gaining acceptance in research today. This acceptance is partly due to the fact that the calipers used to measure skinfolds are light and mobile, reasonably valid in predicting specific gravity, and much more sensible for general population studies than the more unwieldy, elaborate equipment necessary for hydrometry, ultrasound, whole body potassium and hydrostatic weighing (8,18,25,26,42, 45,48,55,56).

The skinfold method has its basis in the constant, proportional distribution of fat between subcutaneous tissue and other sites (23,24,27,41). Changes in the thickness of folds at various body sites are proportional (23,24,28) so that measurement of the subcutaneous fat layer at different times would provide an estimate of the change in total body fat of a person (41).

Fat patterns are dependent on the age and sex of the individual. Edwards states (23:311);

> "The pattern is identical in both sexes before puberty. With the advent of puberty significant differences in the pattern develop, the main difference being that women have about 1.25 times as much fat on their legs as men in proportion to the total amount of fat. Pregnancy and obesity have little or no effect upon the pattern."

The effectiveness of skinfold measurement as a predictor of body fat depends on various circumstances, a few being; the reliability of the tester and the equipment, the relative obesity of the individual (41), the choice and accessibility of skinfold sites, and the ease with which the fold can be lifted from the underlying muscle and fascia. More important still is the validity of the site as an index of total body fat.

Skinfolds as an Estimate of Body Density

Different prediction equations have been developed by researchers attempting to find the combination of skinfolds that would best estimate body density or specific gravity. Unfortunately, the conditions under which these equations were developed are not always similar, and any comparison must be made with this in mind.

Young et al (57) found that when standard weight was included as a variable in the prediction equation, there was no significant advantage in predicting specific gravity by using various combinations of skinfolds over using one. Using the 'pubic' skinfold and standard weight, she reported a correlation of .699 between measured and predicted specific gravities.

Sloan et al (49) were not able to verify this conclusion because they measured the pubic skinfold on a horizontal plane where Young et al (57) had measured it on a vertical plane. Sloan reported a high correlation using the tricep and iliac crest skinfolds. Lately Sloan and Weir (50) have presented a nomogram enabling both body density and percentage of body fat to be read off directly from the appropriate skinfold measurements.

Katch and Michael (35), like Young were able to correlate density with a single skinfold; in their

case, the tricep skinfold. However, the addition of the iliac and scapula skinfolds, and the buttock, abdomen and arm girths increased this correlation to .72 from .58. Katch and Michael concluded that skinfolds alone do not give the best results, with their sample.

Durnin and Rahaman (18) reported correlations of .86 for men and .96 for women between body density and the logarithmic value of the sum of four skinfolds; bicep, tricep, scapula and iliac.

In a study on children, Parizkova found for girls, aged 13 to 16, the subscapular skinfold correlated best with density. The highest multiple correlation however, was recorded from the combination logarithmic value of the subscapular and tricep skinfolds (42).

The technique of measuring skinfolds with calipers is widely used today. Most of the early caliper models were unsatisfactory because the pressure of the jaw closing was controlled by a spring, making the tension at a small opening low, but increasing rapidly as the jaws were opened. The readings depended on the strength of the spring since skin and adipose tissue are compressible (26,37).

Whatever the pressure, it was important for it to be constant from reading to reading and over the range of skinfold thicknesses (37).

A caliper was designed in 1953 by Keys and Brozek (37) which could be set at any constant desired pressure between 5 and 20 $gm/mm^2$, and which would retain this pressure over all openings.

Edwards et al (26) later conducted an investigation into caliper design. They concluded that pressure had a great effect on the thickness of the fold and the consistency of repeated measurements. The face area of the jaw surfaces was negligible by comparison. They recommended a pressure between 9 and 19 $gm/mm^2$ and suggested a standard of 10 $gm/mm^2$. The Harpenden Caliper was developed, partly as a result of this study.

The Best Caliper was designed in 1953 at the U.S. Army Medical Nutrition Laboratory. This caliper has jaw surfaces which are always parallel and a spring tension which is constant regardless of the degree to which the calipers are open (6). Originally the caliper had a jaw pressure of 28.5 $gm/mm^2$ (6,48) but now the pressure has been reduced to 10 $gm/mm^2$.

## Estimation of Percent Body Fat

Exact knowledge of the body composition of man must come from direct studies on man. Studies have been completed using anatomical and chemical analysis

of human cadavers, to discover the relationship between fat and fat-free components of the body. Many of them (5,37,39,51) agree that fat is the component which causes the greatest variation in body density, and also acknowledge the fact that the fat-free components are not constant for all individuals (2,4,39).

From the knowledge of the fat content of guinea pigs, Rathbun and Pace (44) proposed the following formula in 1945 for the prediction of percent body fat.

$$\% \text{ Fat} = 100 \left(\frac{5.548}{\text{specific gravity}} - 5.044\right)$$

This formula was based on the assumption that the specific gravity of fat and fat-free components was 0.918 and 1.100 respectively.

Later, Keys and Brozek (37) developed a formula for a "Reference Man" with a density of 1.0629 and 14% body fat. This formula,

$$\% \text{ Fat} = 100 \left(\frac{4.201}{\text{density}} - 3.813\right)$$

was later revised by further study and a "Reference Body" was formulated to replace the "Reference Man". A new equation was set on the basis of a Reference Body with 15.3% body fat and a density of 1.064 (12). This latest formula is:

$$\% \text{ Fat} = 100\left(\frac{4.950}{\text{density}} - 4.500\right)$$

All these equations unfortunately, were based on data obtained from male subjects, so their complete validity in relation to females is questionable (18).

# CHAPTER III

# METHODS AND PROCEDURES

## Subjects

Eighteen female subjects were randomly selected from Physical Education students at the University of Alberta. The selection was made in this way to approximate the populations on which Katch and Michael (35), Sloan et al (49), and Young et al (57), developed their regression equations, and to which the present sample would be compared.

## Introduction

Each subject came for two sessions, no more than eight days apart. At each session, eight skinfolds were taken with one of the calipers, and then again with the other caliper. The subject then entered a densitometry tank and stood so that the level of water was at her neck. She was then connected to the Godart Pulmotest and asked to breathe normally for approximately five minutes during which time co-ordinates used to calculate residual volume and vital capacity were measured.

Density was then calculated from hydrostatic

weighing. Measurements were taken at maximal inhalation and maximal exhalation, in random order.

From the skinfold measures that correlated well with density, a regression formula was developed. From one to eight skinfolds were used, in various combinations.

Using the regression formulas developed by Young et al (57), Sloan et al (49), Katch and Michael (35) and this study, density was estimated from skinfolds. The four estimates of density were then compared to each other and to the criterion density measure obtained by hydrostatic weighing. The characteristics of each regression formula are:

YOUNG et al:(57) skinfold and percentage standard weight.

Based on 94 females between the ages of 16 and 30.

- Specific Gravity $= 1.0884 - 0.0004231\ X_1 - 0.0003401\ X_{13}$

where $X_1$ = skinfold on mid-abdominal line halfway between umbilicus and pubis (mm).

$X_{13}$ = percentage 'standard' weight (average weight per height and age (15)).

SLOAN et al: (49) skinfolds. Based on 50 females between the ages of 17 and 25.

- Density $= 1.0764 - 0.00081\ X_2 - 0.00088\ X_3$

where $X_2$ = skinfold thickness over the iliac crest (mm).

$X_3$ = skinfold thickness over the back of the arm (mm).

KATCH and MICHAEL: (35) skinfolds and girth measurements.

Based on 64 college females aged 19 to 23.

$$\text{-Density} = 1.12569 - 0.001835\ X_1 - 0.002779\ X_2 + 0.005419\ X_3 - 0.0007167\ X_4$$

where $X_1$ = tricep skinfold (mm).
$X_2$ = buttock girth (in).
$X_3$ = upper arm girth (in).
$X_4$ = scapula skinfold (mm).

Reliability coefficients were calculated for the techniques of inhalation and exhalation during hydrostatic weighing. The most reliable respiration technique, along with the measured residual volume was then used to estimate body density.

Predictive equations developed by Rathbun and Pace, Brozek et al, and Siri were used to estimate percent body fat from the criterion measure of body density. The three estimates of body fat were then compared to each other.

## Calculation of Residual Volume

Residual volume and vital capacity were measured using a Godart Pulmotest and Pulmo-analysor. In brief, it consists of introducing a given concentration of helium into a constant-volume spirometer circuit. It is assumed at the onset that no helium is present in the subject's lungs. The subject breathes into the apparatus, and after a number of breaths there is a

complete equilibrium between the concentrations of helium in the apparatus and in the subject's lungs. The lung volume of the subject may now be determined as follows: the volume of the closed circuit is predetermined. When the equilibrium between the subject's lungs and the apparatus is complete, a new volume can be calculated from the degree of helium dilution. The figure represents the volume of the machine plus the new, unknown volume of the subject's lungs. Subtracting the volume of the apparatus from this will give the functional residual capacity. Subtracting the expiratory reserve volume (measured directly from the recording) from the functional residual capacity will give the residual volume.

Hydrostatic Weighing

A rectangular tank constructed of concrete was used for the underwater weighing. The tank was ten feet by four feet, and could be filled to a depth of five feet.

Stainless steel cables were used to suspend an aluminum chair in the centre of the tank. The cables were connected to a strain guage suspended from the ceiling. A Sargent Recorder was used to amplify and

record the force acting upon the load cell of the strain guage.

Since the weight underwater was recorded during maximal inhalation, a weighted belt with an underwater weight of 18.08 pounds, was used to prevent flotation of the subject.

Procedure

Each subject, wearing a nylon bathing suit, was weighed in air.

The subject then entered the tank and stood with the water at neck level.

Vital capacity and residual volume were measured in this position by the closed circuit helium technique.

The subject then sat in the chair, air bubbles that had collected on her were dislodged, and the weighted belt was attached to her.

Instructions were given for the techniques of inhalation and exhalation. For the former, the subject was told to breathe in as much as possible, then lower herself underwater and hold the position for a few seconds. For exhalation she was instructed to hyperventilate four to five times, breathe out as completely as possible while lowering herself underwater, and then hold the position for as long as she could. The purpose

of hyperventilation was to lower the carbon dioxide tension of the subject's blood so that her 'need' to breathe would not be as great, and she could stay underwater long enough for a steady recording to be taken.

The highest recording was taken if it was repeated, and if not, the average of the two highest readings was taken as the subject's score.

Skinfold Technique

Skinfold thicknesses were measured using two calipers, the Harpenden and Lange. They are both calibrated to exert a constant pressure of 10 gm/mm$^2$.

The locations of the skinfold sites were determined and marked with ink.

Skinfolds were lifted by grasping the fold between the thumb and forefinger of the left hand. The calipers were applied about one centimater from the fingers and at a depth approximately equal to the thickness of the fold.

The sequence of folds was measured twice, each with a different caliper, and approximately five minutes apart. The order of calipers was random.

On the second day, the sequence of measurement was repeated with each caliper. The location of sites was determined from the pen mark of the previous day.

The order of caliper used was again by random selection.

Skinfold Sites

Triceps: located on the dorsal side of the arm, halfway between the tip of the olecranon process and the acromion process. The arm was hanging freely during measurement.

Biceps: over the mid-point of the muscle belly with the arm bent at a $90^{\circ}$ angle.

Subscapular: measured at the tip of the scapula, on a $45^{\circ}$ angle medially upwards.

Lower Rib: located on the lateral aspect of the thorax over the lower rib, midway between the axilla and iliac crest.

Suprailiac: located medial to the anterior superior iliac spine. The fold was lifted at a $45^{\circ}$ angle, laterally upward. The subject was in a supine position with her knees flexed and feet flat on the bench.

Umbilical: located one and one half inches lateral to the umbilicus. The subject was in a supine position.

Abdominal (pubic): located halfway between the umbilicus and the symphysis pubis, on the mid-line of the body. The subject was in a supine position.

All the skinfolds, unless otherwise indicated,

were lifted on a plane, vertical with the long axis of the body.

The subject was standing for all measurements except the suprailiac, umbilical and abdominal. In these cases she was lying supine with her knees flexed, to aid in relaxing the abdominal muscles.

All skinfolds, other than those taken on the mid-line of the body, were measured on the right side.

In addition, two girth measurements were taken with a steel tape; the buttocks girth around the fullest part of the buttocks, and the upper arm girth around the fullest part of the upper arm, over the relaxed triceps.

## Statistical Analysis

All analyses were made at the .05 level of significance.

The Pearson Product-Moment Coefficient of Correlation was used to test for:

a) reliability of each of two caliper designs.

b) reliability of density employing the technique of hydrostatic weighing during maximal inhalation.

c) reliability of density employing the technique of hydrostatic weighing during maximal exhalation.

A one-way analysis of variance was used to test the significance of the difference between the means of:

a) density obtained by hydrostatic weighing and by skinfold equations.

b) percent body fat obtained from three predictive formulas.

Duncans New Multiple Range Test (21) was used to determine which estimates of density, obtained from skinfold equations, differed from the density as obtained by hydrostatic weighing.

## CHAPTER IV

## RESULTS AND DISCUSSION

### Characteristics of the Subjects

The average age, height and weight of the eighteen subjects is recorded in Table I.

Table I

Age, height and weight of subjects

| Variable | Mean | Standard Deviation | Range |
|---|---|---|---|
| Age (yr.) | 20.0 | 1.78 | 18-25 |
| Height (in.) | 64.5 | 2.84 | 60-70 |
| Weight (Kg.) | 61.1 | 8.81 | 48.6-80.0 |

Table II shows the mean ages, weights, heights, and percent body fat of the subjects in the four different studies under consideration. The subjects of the present study are as old as those studied by Young et al (57), Sloan et al (49) and Katch and Michael (35), however their mean body weight (61.1 Kg.) is slightly higher, and their mean height (64.5 in.) slightly lower than the subjects of those studies.

Table II

Age, height, weight and percent body fat of subjects

| Study | Age (yr) | Height (in) | Weight (kg) | % Fat |
|---|---|---|---|---|
| Young et al (57) | 16-30 | 65.94 | 59 ± 6.45 | 28.69 |
| Sloan, Burt, Blyth (49) | 17-25 | 64.96 | 56 ± 5.9 | 22.13 |
| Katch and Michael (35) | 19-23 | 65.31 | 58 ± 6.7 | 21.5 |
| Present Study | 18-25 | 64.5 | 61 ± 8.81 | 21.06 |

Although the subjects in the present study have slightly heavier body weights, they have a lower percentage of body fat than in the previously mentioned studies. Other studies have mentioned this increase in body weight and decrease in body fat in physically active people (14,32).

## Skinfold Measurements

Two measurements were taken with each caliper on each skinfold site. The Pearson-Product Moment Correlation was used to test for reliability at each skinfold site. Table III records these reliability coefficients.

Table III

Reliability coefficients for the Harpenden and Lange Calipers at each skinfold site

| Site | Harpenden Caliper | Lange Caliper |
|---|---|---|
| Triceps | .97 | .96 |
| Biceps | .97 | .95 |
| Subscapula | .95 | .96 |
| Waist | .98 | .92 |
| Pubis | .98 | .95 |
| Umbilicus | .99 | .98 |
| Lower Rib | .98 | .92 |
| Suprailiac | .99 | .98 |
| Total | .996 | .989 |

In only one instance, the subscapular skinfold, was the reliability for the Harpenden Caliper lower than that for the Lange Caliper. The Harpenden Caliper could be read more accurately because it is marked off in tenths of a millimeter, and also because the dial faces up in all measurements, making the readings easier to see. The Lange Caliper has moveable jaw surfaces which tend to slip on the thicker skinfold sites, making repeated measurements necessary. This was not so with the Harpenden Caliper. It was able to grip

every skinfold firmly, without slipping, and this difference, it was felt, is due to the fixed jaw surfaces of the Harpenden Caliper.

Because the overall reliability of the Harpenden Caliper was greater than that of the Lange, all skinfolds used to predict body density were those taken with the Harpenden Caliper. However, when readings, taken with the Lange caliper were substituted for those taken with the Harpenden, there was no significant difference at the .05 level in the densities recorded.

The mean, standard deviation and range of girth measurements and of skinfold thicknesses for the Harpenden and Lange Calipers are shown in Table IV. Since there were two measures taken at each skinfold site for each caliper (test-retest), the average of the two recordings for each caliper was assumed as the most representative score, and used in the calculation of the mean, standard deviation and range.

In one subject, at the pubic site, the skinfold was too firm to lift and measure with the calipers. In this case, the average pubic measurement of the remaining seventeen girls was taken as this subject's skinfold measurement. Difficulty in measuring skinfolds was encountered only at the pubic site, which was located halfway between the umbilicus and the symphysis pubis on the midline of the body.

Table IV

Skinfold thickness and girth measurements

| Caliper | Site | Mean | Range |
|---|---|---|---|
| Harpenden | Triceps | 15.9 ± 5.2 | 9.3 - 29.2 |
| Lange | Triceps | 17.5 ± 6.0 | 9.3 - 31.5 |
| Harpenden | Biceps | 6.1 ± 2.0 | 3.7 - 11.3 |
| Lange | Biceps | 6.3 ± 3.1 | 2.7 - 11.7 |
| Harpenden | * Subscapular | 12.1 ± 4.2 | 7.4 - 21.6 |
| Lange | Subscapular | 13.4 ± 6.0 | 7.2 - 26.5 |
| Harpenden | Waist | 18.7 ± 7.2 | 10.1 - 38.5 |
| Lange | Waist | 21.4 ± 8.1 | 10.1 - 38.8 |
| Harpenden | Pubis | 19.2 ± 8.3 | 10.6 - 36.2 |
| Lange | Pubis | 21.1 ± 9.0 | 10.6 - 42.9 |
| Harpenden | Umbilicus | 13.3 ± 7.1 | 6.8 - 37.3 |
| Lange | Umbilicus | 15.7 ± 9.2 | 6.7 - 44.1 |
| Harpenden | Lower Rib | 10.6 ± 4.7 | 5.1 - 22.7 |
| Lange | Lower Rib | 10.5 ± 4.9 | 4.9 - 20.7 |
| Harpenden | * Suprailiac | 9.3 ± 5.1 | 4.7 - 21.3 |
| Lange | Suprailiac | 10.5 ± 6.3 | 4.2 - 25.9 |
| Harpenden | Total | 105.1 ± 40.8 | 63.2 - 209.8 |
| Lange | Total | 116.9 ± 60.3 | 66.7 - 235.5 |

* significantly different at the .05 level of significance.

| | | | |
|---|---|---|---|
| | Buttocks girth (in) | 37.5 ± 1.9 | 33.7 - 42.3 |
| | Upper Arm girth (in) | 10.5 ± 1.5 | 5.9 - 12.3 |

A comparison of skinfolds from different studies is presented in Table V.

Table V

A summary of skinfold thicknesses and girths recorded in a number of investigations

| Site | Present Study | Young et al (57) | Sloan et al (49) | Katch and Michael (35) | Booth (7) |
|---|---|---|---|---|---|
| Triceps (mm) | 15.9 | 25.43 | 16.08 | 12.31 | 15.39 |
| Subscapular (mm) | 12.1 | 12.07 | | 10.81 | 10.72 |
| Lower Rib (mm) | 10.6 | 10.46 | | | 9.27 |
| Waist (mm) | 18.7 | 14.65 | | 16.49 | 11.68 |
| Suprailiac (mm) | 9.3 | 20.74 | 19.16 | | 9.28 |
| Umbilicus (mm) | 13.3 | 22.93 | | 15.19 | 9.39 |
| Pubic (mm) | 19.2 | 33.04 | 19.4 | | 15.41 |
| Buttock girth (in) | 37.55 | | 36.49 | 37.38 | |
| Upper Arm girth (in) | 10.46 | | 9.63 | 10.53 | |

When the present skinfold values were compared to those of Young et al (57), similar results were obtained for the subscapular, lower rib and waist sites. The

triceps, suprailiac, umbilicus and pubic sites, however, were much lower for this study. The three skinfold values from Sloan et al (49) compared more favorably although again, the suprailiac skin fold in the present study was lower. This is probably because the suprailiac fold was measured on the mid-axillary line by both Young (57) and Sloan (49), whereas it was measured at a 45° angle medially downward in the present study and in that of Booth (7). Skinfolds taken by Booth (7) and the present study compare most favorably. Each study was done on physical education women from the University of Alberta. However the subjects used were not the same because the studies were two years apart. The skinfold measures of Katch and Michael (35) compare favorably with this study.

The buttocks and upper arm girths of the present study are very similar to those of Katch and Michael, and only slightly higher than those measured by Sloan et al.

Density Estimates from Skinfolds, Using a Stepwise Regression

The coefficient for the correlation between the skinfolds from the individual sites and body density from hydrostatic weighing are recorded in Table VI. The corresponding coefficients obtained by Young et al,

Sloan et al, Katch and Michael and Booth are included to permit comparison.

Young (57) found that body density correlated most highly with the pubic skinfold. Katch and Michael (35) and Booth (7) reported their highest simple correlation to be with the triceps skinfold, whereas both Sloan (49) and the present study found the best simple correlation occured with the lower rib skinfold followed by the triceps.

Table VI

Correlation coefficients between skinfold thicknesses and body density

| Skinfold Site | Present Study | Young et al (57) | Sloan et al (49) | Katch and Michael (35) | Booth (7) |
|---|---|---|---|---|---|
| Triceps | -.67 | -.52 | -.54 | -.59 | -.49 |
| Biceps | -.66 | | | | |
| Subscapula | -.58 | -.52 | | -.55 | -.31 |
| Waist | -.66 | -.60 | | -.42 | -.25 |
| Pubis | -.62 | -.66 | -.52 | | -.32 |
| Umbilicus | -.44 | -.60 | | -.33 | -.48 |
| Lower Rib | -.72 | -.61 | -.65 | | -.34 |
| Suprailiac | -.53 | -.63 | -.61 | | -.42 |

Multiple regression equations were calculated to predict body density from various combinations of skinfolds. The eight skinfolds from the present study were used as predictor variables, and density as calculated by hydrostatic weighing, was used as the criterion variable. All coefficients of multiple correlation that were not significantly different from zero at the .05 level of significance, were omitted from further calculation.

In the present study, the lower rib skinfold was the best single predictor of density, accounting for 51% of the variance. The best combination of skinfolds, accounting for 69% of the variance, was the umbilical and lower rib skinfold. The addition of other skinfold measurements failed to increase this correlation. The corresponding regression equation is:

$$Y = 1.073 + 0.001682\ X_6 - 0.00423\ X_7$$

where $Y$ = density (gm/ml)

$X_6$= umbilical skinfold (mm)

$X_7$= lower rib skinfold (mm)

Table VII records the prediction equations which were significantly different from zero at the .05 level of significance.

Table VII

Prediction equations of body density

from skinfold measurements

| Variable | Coefficient | Multiple Correlation | STD Error |
| --- | --- | --- | --- |
| Constant | 1.071 | | |
| 7 | -0.001984 | .51 | 0.000484 |
| | | | |
| Constant | 1.073 | | |
| 6 | 0.001682 | | 0.000564 |
| 7 | -0.004230 | .69 | 0.000851 |

Body Density and Fat Content

Only a few studies have been done predicting body density from skinfolds in young women. Young(57) found that the pubic skinfold and standard weight gave the highest correlation with density, and Sloan (49) reported that the triceps and iliac skinfolds were the best predictors of density. Katch and Michael (35) included the upper arm and buttock girths with the tricep and scapula skinfolds to give their best estimation of body density.

The above three formulas and the regression equation developed from this study were used to estimate body density from skinfolds. Percent fat of body weight was calculated for all using the Brozek equation (12). The results are presented in Table VIII. Young (57) and Sloan (49) both gave values that were statistically similar to the criterion measure of body density, but the Katch and Michael equation gave a significantly different value at the .05 level of significance.

Density Measurements from Hydrostatic Weighing

Four different methods of hydrostatic weighing were used to calculate body density. Residual volume was measured immediately prior to the weighing with the

Table VIII

Mean, standard deviation and range of percent body fat*, using density values estimated from four different equations

*(according to Brozek (12))

| Equation | Mean | Standard Deviation | Range |
|---|---|---|---|
| Young et al (57) | 22.66 | 2.61 | 19.42-28.75 |
| Sloan et al (49) | 22.26 | 4.08 | 19.63-31.17 |
| Katch and Michael (35) | 25.12** | 4.57 | 18.23-33.66 |
| Regression from Present Study | 20.91 | 4.51 | 12.78-30.82 |

**The average percent body fat calculated using body density from the Katch and Michael equation is significantly different from the remaining three values at the .05 level of significance.

helium dilution technique, and each subject was weighed both in a condition of full inspiration and full expiration. The reliability of determining the residual volume was r = .689. In the analysis of results, residual volume was estimated at 30% of the vital capacity to permit a comparison of results between body density calculated from a predicted and from a measured residual volume. The reliabilities of the test-retest for the four different hydrostatic determinations of body density are recorded in Table IX.

Table IX

Reliability for hydrostatic determinations of body density

| Method | Reliability |
|---|---|
| Inspiration - measured residual volume | .95 |
| Expiration - measured residual volume | .94 |
| Expiration - estimated residual volume | .93 |
| Inspiration - estimated residual volume | .89 |

Although all reliabilities were high, the method of Inspiration with a determined residual volume reported the highest reliability (.95), and these density scores

were used later in the comparison of percent body fat as predicted by the formulas of Brozek (12), Siri (47) and Rathbun-Pace (44).

Analysis of Variance

Eight methods of determining body density were used in this study: four from hydrostatic weighing;

inspiration - residual volume measured
expiration - residual volume measured
inspiration - residual volume estimated
expiration - residual volume estimated

and four from skinfold equations;

Young et al (57)
Sloan et al (49)
Katch and Michael (35)
Regression from this study.

These eight estimations of body density were converted to percent body fat by the Brozek formula, and compared in a one-way analysis of variance to find out if there was a significant difference between any of the estimates.

The method of inspiration with a measured residual volume was chosen because it had the highest reliability in a test-retest situation. Table X records the mean, standard deviation and range of percent body fat as converted by the Brozek formula.

Table X

Mean, standard deviation and range of percent body fat from density determined by eight different methods

| Method | Mean | Range |
|---|---|---|
| Regression equation from Present Study | 20.91 ± 4.1 | 12.78 - 30.82 |
| Inspiration - measured residual volume | 21.06 ± 5.4 | 12.82 - 32.20 |
| Inspiration - estimated residual volume | 21.52 ± 4.8 | 14.45 - 31.15 |
| Sloan et al (49) | 22.26 ± 4.1 | 16.63 - 31.17 |
| Young et al (57) | 22.66 ± 2.6 | 19.42 - 28.75 |
| Expiration - measured residual volume | 24.39 ± 4.7 | 15.44 - 33.95 |
| Expiration - estimated residual volume | 24.71 ± 4.4 | 16.16 - 33.37 |
| Katch and Michael (35) | 25.23 ± 4.6 | 18.23 - 33.66 |

At the .05 level of significance there was a significant difference between the eight means. A Duncan New Multiple Range Test (21:136) was used to show which means were significantly different from the criterion mean calculated by the method of inspiration - residual volume measured. (Table XI)

Table XI

A summary of the Duncan New Multiple Range Test -

for calculated values of percent body fat

| METHOD | Regression from Present Study | Inspiration residual volume measured | Inspiration residual volume estimated | Sloan et al (49) | Young et al (57) | Expiration residual volume measured | Expiration residual volume estimated | Katch and Michael (35) |
|---|---|---|---|---|---|---|---|---|
| MEAN | 20.91 | 21.06 | 21.52 | 22.26 | 22.66 | 24.39 | 24.71 | 25.23 |

Those means underscored by the same line do not differ significantly at the .05 level of significance. Those means that are not underscored by the same line do differ significantly at the .05 level. The two methods of hydrostatic weighing which used expiration, although they reported high reliabilities in a test-retest situation (.94 and .93 respectively) gave significantly different density measures from the criterion value.

Many studies on hydrostatic weighing are now being done using the technique of expiration (30,34,36, 43,52). In a study done by Katch (34) the subjects expired maximally and then held their breath for five seconds while being weighed. The subjects of the present study found it very difficult to hold their breath this long even after hyperventilating to lower their blood carbon dioxide content and thus lowering their 'need' to breathe. Consequently, each subject recorded as many as five or six values for the expiration technique before two values were close enough to warrant a true recording. They also had trouble exhaling and holding their breath long enough for a steady reading to be taken on the recorder. No more than two to three inspirations were needed however, for a recording. It is felt that the subjects of this study preferred the idea of inhaling to exhaling before submerging

themselves, and thus there was less trouble with them using that method. There were also complaints of their lungs hurting too much when they blew out all their air and then held their breath. As a result of this difficulty in obtaining a recording with the expiration technique and in spite of its high reliability, it was felt that the inspiration rather than expiration method should be used as the criterion to which all other methods would be compared.

Formulas for Predicting Percent Body Fat

The most reliable method of estimating body density was underwater weighing with inspiration and a measured residual volume. The averages of these scores were substituted into three different formulas for the prediction of percent body fat. The formulas were those of Brozek (12), Rathbun-Pace (44) and Siri (47). A one-way analysis of variance was then used to test for a significant difference between the three means. Table XII gives the mean, standard deviation and range of scores as predicted by the three different formulas.

Table XII

Mean, standard deviation and range of percent body fat as estimated by three different formulas

| Formula | Mean | Range |
|---|---|---|
| Brozek (12) | 21.06 ± 5.41 | 12.82 - 32.00 |
| Rathbun-Pace (44) | 24.07 ± 6.55 | 14.00 - 37.55 |
| Siri (47) | 21.51 ± 5.84 | 12.53 - 33.54 |

Although the Rathbun-Pace formula gives a higher percent body fat than do the formulas of Brozek and Siri, no significant difference was found between the means at the .05 level.

This in agreement with Wilmore and Behnke (54,55) who also reported a non-significant difference between the three formulas. Brozek, however, in two different articles (9,12) found that the Rathbun-Pace formula gave a significantly higher value than the other two formulas. Booth (7) found the same thing in a Master's Thesis done on Physical Education students from the University of Alberta.

CHAPTER V

# SUMMARY AND CONCLUSIONS

## Summary

The purpose of this study was:

1. to compare the reliability of two different makes of calipers in the measurement of skinfold thicknesses.

2. to investigate the accuracy with which the skinfold regression formulas developed by Young et al (57), Sloan et al (49) and Katch and Michael (35) would predict body density of a group of physical education students, and to develop another regression equation which might be more applicable to physically active students.

3. to compare the reliability of two techniques of hydrostatic weighing, those of inhalation and exhalation, and to test for significance the density measures of each technique.

4. to discover whether or not calculating the residual volume, rather than estimating it, would significantly change measures of body density.

5. to compare three equations used to estimate percent body fat from density. Those of Brozek (12), Rathbun-Pace (44) and Siri (47) were used.

Eighteen randomly selected female physical education students from the University of Alberta participated in the study. Skinfolds were measured with the Harpenden and Lange calipers according to the technique outlined by Brozek (11). Two measures were taken with each caliper, and reliability was tested for each site and each caliper using the Pearson-Product Moment Correlation. The most reliable measurements were substituted into the regression formulas of Young (57), Sloan (49) and Katch and Michael (35) and a regression equation developed from this study.

Body density was measured hydrostatically using the techniques of inspiration and expiration. Residual volume was calculated using the helium dilution technique. Body density was calculated in four different ways using the technique of inspiration with a measured residual volume, expiration with a measured residual volume, inspiration with an estimated residual volume, and expiration with an estimated residual volume. The most reliable density measure, using inspiration with the residual volume measured, was used as the criterion measure.

The eight measures of body density were then compared in a one-way analysis of variance to test for a significant difference between the means.

The criterion measure of body density was then substituted into three different equations developed by Brozek (12), Rathbun-Pace (44) and Siri (47), and a one-way analysis of variance was used to test the degree of consensus among them.

## Conclusions

Within the limitations of this study, the following conclusions were made.

1. The Harpenden Caliper is more reliable than the Lange as indicated by the higher reliabilities reported at all but one skinfold site.

2. The skinfold regression formulas developed by Young (57) and Sloan (49) do give an accurate estimate of body density for physical education women. This was indicated by a non-significant coefficient of correlation at the .05 level of significance. The Katch and Michael formula (35) however, reported a significant correlation, indicating that it does not give an accurate estimate of body density for the women of this study. A regression equation developed in this study showed that a combination of umbilical and lower rib skinfolds proved to be the best sites in predicting

body density.

3. The technique of inspiration in underwater weighing reported a slightly higher reliability than the technique of expiration. The mean score given by the expiration technique however, was significantly different from that recorded by the technique of inspiration at the .05 level.

4. Calculating the residual volume rather than estimating it did not affect a significant change in body density when the mean of the scores was taken.

5. At the .05 level of significance there was no difference in the scores of percent body fat as predicted by three different equations.

Recommendations

1. That a pilot study be done on the Pulmotest comparing results before and after a period of training in the use of the machine.

2. That a technician be trained in the use of the Godart Pulmotest and that he conduct all tests done on it,

OR

3. That a pilot study to gain experience with the Pulmotest, be done prior to every major study using this machine.

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# APPENDICES

# APPENDIX A

# STATISTICAL PROCEDURES AND SAMPLE CALCULATION SHEETS

The Difference Between Two Means for Correlated Samples

The difference between body density estimated by two different sets of skinfolds (two different calipers) was tested for significance using the Olivetti Underwood Programma 101, code 5.20.

$$t = \frac{|\bar{X}_1 - \bar{X}_2|}{\hat{\sigma}_{\bar{X}_1 - \bar{X}_2}}$$

where $X_1$ = arithmetic mean of sample 1

$X_2$ = arithmetic mean of sample 2

$\hat{\sigma}\ \bar{X}_1 - \bar{X}_2$ = estimated standard error of the difference.

Correlation Coefficients

All reliability and correlation coefficients were calculated using the Pearson product-moment correlation,

$$r = \frac{N\sum xy - \sum x \sum y}{\sqrt{(N\sum x^2 - (\sum x)^2)(N\sum y^2 - (\sum y)^2)}}$$

where r = the simple correlation coefficient between x and y

x = all the x values

y = all the y values

N = the number of observations

## Multiple Regression Equations

Multiple regression equations were calculated to predict the body density from various combinations of skinfolds. The estimates obtained were correlated with the measured body density, yielding multiple correlation coefficients. The calculations were made using the IBM System 360/67 programme MULRØ6. This program calculates the stepwise regression using the method of Draper and Smith (1966). The advantage that this program has over the usual method of calculating a stepwise regression is that one may specify the level of significance for adding and for deleting predictor variables (17:180).

## Coefficient of Multiple Determination

The coefficient of multiple determination or $R^2$ gives the proportion of variance in the dependent variable which is predicted by the multiple regression equation.

## Analysis of Variance

A one-way analysis of variance (22:117) was used to test the difference between estimates of percent body fat obtained from eight different methods of prediction, and between percent body fat obtained from the three formulas. The calculations were made using the IBM System 360/67 Anova 2.

<u>Dunnett's Multiple Comparison</u>

All the predictions of body density were compared to the criterion measure using Dunnett's multiple comparison in which the control mean is compared to each treatment mean. The difference is significant if (22:150):

$$t = \frac{(\bar{x}_k - \bar{x}_o)}{2s^2/n} \quad \text{critical } t_{k,(n-1)} + k(n-1)$$

where $\bar{x}_k$ = the mean of any given treatment group

$\bar{x}_o$ = the mean of the control group

$s$ = the error mean square of the analysis of variance

$n$ = the number of observations

$k$ = the number of treatment groups

ESTIMATION OF BODY COMPOSITION

| MEASUREMENTS | POUNDS | LITRES | CUBIC INCHES |
|---|---|---|---|
| Wt. in air | ____ | | |
| Vital Capacity (VC) | | ____ | ____ |
| Residual Volume (RV) | | ____ | ____ |
| Volume Gastro-Intestinal (VGI) | | | ____ |
| Wt. in water | ____ | | |

CALCULATIONS

Total lung capacity (TLC) = ____(VC) + ____ (RV) + ____(VGI)

= ____ TLC cu. in.

____TLC cu. in. x 0.0362 = ____TLC lbs.

True Wt. = ____ (Wt. in water) + ____ (TLC lbs.) = ____

Body Volume = ____ (Wt. in air) - ____ (True Wt.)

Body Density = ____ (Wt. in air)/____ (Body Volume)

x ($H_2O$ Density) = ____

Specific Gravity = ____ (Body Density)/____ ($H_2O$ Density)

= ____

Rathbun-Pace (1945) % fat = (5.548/Specific Gravity) - 5.044 = ____%

Brozek et al (1963) % fat = (4.570/Density) - 4.142

= ____%

Siri (1963) % fat = (4.950/Density) - 4.500

= ____%

Lbs. Fat = ____ (% Fat) x ____ (Wt.) = ____ lbs.

Lbs. Fat Free = ____ (Wt.) - ____ (lbs. Fat) = ____ lbs.

SKINFOLD MEASUREMENT

| Site | Harpenden Caliper 1 | 2 | Mean | Lange Caliper 1 | 2 | Mean |
|---|---|---|---|---|---|---|
| Triceps | | | | | | |
| Biceps | | | | | | |
| Subscapular | | | | | | |
| Waist | | | | | | |
| Pubis | | | | | | |
| Umbilicus | | | | | | |
| Lower Rib | | | | | | |
| Suprailiac | | | | | | |

LUNG VOLUME

Initial Helium = ____ Dead Space Volume = 9.37 L.

Final Helium = ____

Temperature = _____

Functional Residual Capacity = (Initial Helium - Final Helium) x (Dead Space Volume)/ Final Helium

Vital Capacity = ____ (height of graph reading in mm.) x ____ (temperature factor) = ____ L.

Expiratory Reserve Volume = ____ (height of graph reading in mm.) x ____ (temperature factor) = ____ L.

Residual Volume = ____ (FRC) - ____ (ERV) = ____ L.

# APPENDIX B

# CORRELATION MATRICES

Correlation Matrix of Skinfold Measures to the Density

Estimate from Hydrostatic Weighing

| | Tricep | Bicep | Subscapula | Waist | Pubis | Umbilicus | Lower Rib | Suprailiac |
|---|---|---|---|---|---|---|---|---|
| Tricep | 1.00 | .90 | .80 | .75 | .78 | .60 | .72 | .76 |
| Bicep | .90 | 1.00 | .88 | .85 | .79 | .76 | .87 | .83 |
| Subscapula | .80 | .88 | 1.00 | .82 | .81 | .84 | .86 | .87 |
| Waist | .75 | .85 | .82 | 1.00 | .85 | .88 | .95 | .83 |
| Pubis | .78 | .79 | .81 | .85 | 1.00 | .77 | .79 | .94 |
| Umbilicus | .60 | .76 | .84 | .88 | .77 | 1.00 | .89 | .84 |
| Lower Rib | .72 | .87 | .86 | .96 | .79 | .89 | 1.00 | .80 |
| Suprailiac | .76 | .83 | .87 | .83 | .94 | .84 | .80 | 1.00 |
| Density | -.67 | -.66 | -.58 | -.66 | -.62 | -.44 | -.72 | -.53 |

# APPENDIX C

RAW SCORES

Densitometric Measurements

Body density converted to percent body fat

by the formula of Brozek (1963)

| Subject | Method | | | |
|---|---|---|---|---|
| | Inspiration Residual Volume Measured | Expiration Residual Volume Measured | Inspiration Residual Volume Estimated | Expiration Residual Volume Estimated |
| 1 | 20.90 | 23.72 | 24.63 | 27.38 |
| 2 | 15.00 | 20.66 | 17.46 | 22.61 |
| 3 | 12.82 | 15.44 | 15.83 | 18.17 |
| 4 | 18.01 | 25.44 | 16.97 | 24.71 |
| 5 | 16.53 | 22.91 | 21.50 | 23.24 |
| 6 | 26.07 | 28.22 | 24.88 | 16.17 |
| 7 | 19.19 | 23.35 | 23.95 | 25.73 |
| 8 | 18.44 | 23.04 | 17.66 | 23.26 |
| 9 | 25.39 | 29.03 | 25.85 | 29.96 |
| 10 | 20.50 | 24.09 | 17.74 | 23.33 |
| 11 | 14.88 | 16.56 | 12.38 | 16.16 |
| 12 | 22.57 | 24.23 | 19.96 | 22.09 |
| 13 | 29.07 | 33.95 | 28.11 | 33.37 |
| 14 | 32.20 | 31.20 | 30.61 | 29.70 |
| 15 | 16.25 | 19.55 | 17.01 | 20.33 |
| 16 | 24.10 | 25.25 | 23.12 | 24.60 |
| 17 | 27.75 | 28.20 | 25.39 | 27.94 |
| 18 | 19.50 | 24.30 | 22.45 | 26.51 |

Body density converted to percent body fat

by the formula of Brozek (1963)

| Subject | Method | | | |
|---|---|---|---|---|
| | Equation of Sloan et al (49) | Equation of Young et al (57) | Equation of Katch and Michael (35) | Equation from Regression of Present Study |
| 1 | 20.45 | 22.36 | 22.36 | 20.66 |
| 2 | 20.12 | 20.78 | 30.05 | 18.64 |
| 3 | 16.93 | 20.04 | 20.37 | 12.78 |
| 4 | 21.36 | 22.61 | 23.87 | 17.82 |
| 5 | 19.22 | 22.28 | 23.37 | 19.01 |
| 6 | 18.64 | 19.42 | 22.61 | 18.23 |
| 7 | 18.97 | 22.82 | 22.99 | 17.05 |
| 8 | 24.16 | 22.82 | 29.57 | 20.54 |
| 9 | 29.14 | 25.81 | 33.22 | 21.49 |
| 10 | 21.28 | 21.61 | 23.32 | 19.75 |
| 11 | 17.46 | 19.92 | 19.01 | 16.60 |
| 12 | 22.57 | 22.11 | 23.49 | 25.22 |
| 13 | 25.64 | 24.04 | 28.11 | 30.82 |
| 14 | 28.07 | 28.75 | 33.66 | 27.68 |
| 15 | 19.92 | 21.20 | 18.23 | 17.82 |
| 16 | 31.17 | 28.02 | 29.57 | 25.34 |
| 17 | 24.84 | 23.20 | 27.47 | 26.15 |
| 18 | 20.78 | 20.16 | 23.03 | 20.78 |

Skinfold Measurements (mm.)

| Subject | Tricep | | Bicep | | Subscapula | | Waist | |
|---|---|---|---|---|---|---|---|---|
| | Harpenden | Lange | Harpenden | Lange | Harpenden | Lange | Harpenden | Lange |
| 1 | 14.6 | 20.5 | 4.4 | 4.6 | 9.0 | 8.0 | 15.0 | 18.0 |
| 2 | 13.2 | 13.1 | 5.2 | 6.8 | 10.0 | 10.3 | 15.5 | 20.0 |
| 3 | 9.3 | 10.0 | 3.9 | 4.0 | 8.2 | 8.0 | 10.1 | 11.1 |
| 4 | 14.6 | 15.5 | 4.2 | 4.5 | 11.2 | 13.7 | 17.7 | 18.1 |
| 5 | 12.1 | 13.2 | 3.9 | 3.5 | 12.1 | 12.7 | 13.5 | 16.2 |
| 6 | 12.2 | 12.2 | 3.7 | 2.7 | 7.9 | 7.3 | 12.1 | 13.9 |
| 7 | 13.5 | 15.4 | 4.2 | 4.4 | 12.4 | 12.0 | 11.7 | 12.4 |
| 8 | 21.3 | 22.3 | 6.5 | 5.4 | 11.1 | 11.8 | 18.7 | 20.3 |
| 9 | 29.2 | 31.5 | 11.3 | 10.8 | 20.2 | 26.5 | 24.5 | 29.5 |
| 10 | 14.7 | 16.7 | 5.4 | 5.5 | 7.4 | 7.2 | 17.3 | 20.0 |
| 11 | 9.7 | 10.1 | 4.1 | 3.8 | 8.6 | 9.4 | 11.3 | 13.7 |
| 12 | 14.4 | 15.4 | 6.6 | 7.0 | 11.5 | 13.0 | 21.5 | 24.0 |
| 13 | 20.9 | 22.5 | 10.1 | 11.9 | 18.1 | 21.6 | 23.4 | 28.5 |
| 14 | 20.8 | 24.3 | 7.6 | 8.1 | 16.5 | 20.0 | 30.5 | 38.5 |
| 15 | 12.0 | 12.2 | 3.9 | 3.9 | 8.8 | 8.6 | 16.0 | 17.7 |
| 16 | 21.7 | 25.9 | 11.0 | 11.7 | 21.6 | 25.5 | 38.5 | 38.8 |
| 17 | 19.6 | 22.5 | 8.1 | 10.8 | 11.6 | 13.7 | 22.5 | 26.2 |
| 18 | 13.1 | 13.3 | 5.2 | 4.1 | 11.9 | 11.8 | 17.4 | 18.5 |

Skinfold Measurements (mm.)

| Subject | Pubis | | Umiblicus | | Lower Rib | | Suprailiac | |
|---|---|---|---|---|---|---|---|---|
| | Harpenden | Lange | Harpenden | Lange | Harpenden | Lange | Harpenden | Lange |
| 1 | 18.5 | 21.1 | 11.0 | 11.0 | 9.6 | 9.4 | 8.5 | 9.9 |
| 2 | 13.0 | 13.9 | 10.4 | 11.2 | 8.2 | 7.8 | 6.8 | 6.5 |
| 3 | 10.6 | 11.0 | 11.2 | 11.7 | 5.1 | 4.9 | 5.1 | 5.9 |
| 4 | 10.7 | 13.7 | 8.8 | 11.0 | 7.1 | 7.2 | 5.8 | 7.6 |
| 5 | 12.9 | 14.1 | 11.6 | 10.5 | 8.9 | 8.2 | 6.2 | 6.9 |
| 6 | 13.7 | 19.5 | 8.0 | 7.6 | 7.0 | 6.6 | 4.7 | 4.2 |
| 7 | 15.9 | 19.0 | 9.7 | 11.4 | 7.0 | 7.0 | 6.1 | 6.5 |
| 8 | 19.9 | 16.7 | 11.2 | 13.2 | 9.6 | 9.3 | 6.5 | 6.5 |
| 9 | 35.0 | 21.1 | 20.1 | 27.0 | 13.7 | 14.9 | 21.3 | 23.5 |
| 10 | 19.4 | 22.2 | 6.8 | 6.7 | 7.4 | 7.5 | 7.8 | 7.5 |
| 11 | 10.9 | 14.5 | 8.8 | 10.4 | 6.4 | 5.8 | 7.3 | 8.3 |
| 12 | 21.4 | 22.5 | 14.6 | 19.0 | 13.6 | 13.6 | 10.8 | 11.7 |
| 13 | 22.7 | 28.5 | 13.8 | 19.5 | 16.4 | 18.4 | 11.2 | 15.0 |
| 14 | 34.5 | 42.8 | 19.7 | 25.9 | 17.0 | 19.0 | 16.0 | 19.5 |
| 15 | 19.8 | 22.4 | 7.4 | 8.1 | 6.5 | 6.1 | 7.0 | 7.5 |
| 16 | 36.2 | 42.9 | 37.3 | 44.1 | 22.7 | 20.7 | 20.8 | 25.9 |
| 17 | 13.1 | 14.4 | 14.0 | 15.5 | 13.9 | 13.5 | 5.9 | 5.9 |
| 18 | 17.1 | 19.0 | 14.6 | 18.3 | 11.1 | 9.7 | 9.2 | 9.9 |

Girth Measurements (in.)

| Subject | Buttock Girth | Upper Arm Girth |
|---|---|---|
| 1 | 37.8 | 11.0 |
| 2 | 35.0 | 5.9 |
| 3 | 36.8 | 9.4 |
| 4 | 38.3 | 10.9 |
| 5 | 40.2 | 11.3 |
| 6 | 37.7 | 9.8 |
| 7 | 37.5 | 10.6 |
| 8 | 38.4 | 10.7 |
| 9 | 36.6 | 12.1 |
| 10 | 36.5 | 9.7 |
| 11 | 36.0 | 9.8 |
| 12 | 36.1 | 9.9 |
| 13 | 38.6 | 12.2 |
| 14 | 42.3 | 11.5 |
| 15 | 33.8 | 9.8 |
| 16 | 38.5 | 12.3 |
| 17 | 39.9 | 11.8 |
| 18 | 36.0 | 9.6 |

Body Fat Estimated from the Brozek et al (1963), Rathbun-Pace (1945) and Siri (1963) Formulas

| Subject | Percentage Fat | | |
|---|---|---|---|
| | Brozek et al | Rathbun Pace | Siri |
| 1 | 20.90 | 23.84 | 21.29 |
| 2 | 15.00 | 16.63 | 14.87 |
| 3 | 12.82 | 14.00 | 12.53 |
| 4 | 18.01 | 20.38 | 18.21 |
| 5 | 16.53 | 18.50 | 16.54 |
| 6 | 20.07 | 30.08 | 26.87 |
| 7 | 19.19 | 22.72 | 20.30 |
| 8 | 18.44 | 20.82 | 18.61 |
| 9 | 25.39 | 29.26 | 26.14 |
| 10 | 20.50 | 23.32 | 20.84 |
| 11 | 14.88 | 16.49 | 14.74 |
| 12 | 22.57 | 25.84 | 23.09 |
| 13 | 29.07 | 33.71 | 30.11 |
| 14 | 32.20 | 37.55 | 33.54 |
| 15 | 16.25 | 18.20 | 26.27 |
| 16 | 24.10 | 27.73 | 24.77 |
| 17 | 27.75 | 32.15 | 28.72 |
| 18 | 19.50 | 22.12 | 19.77 |

Measurements of Residual Volume

| Subject | Residual Volume (l.) |
|---|---|
| 1 | .8844 |
| 2 | .9480 |
| 3 | .9933 |
| 4 | .8026 |
| 5 | .7898 |
| 6 | .7657 |
| 7 | .7199 |
| 8 | .9573 |
| 9 | 1.3390 |
| 10 | 1.1825 |
| 11 | 1.0882 |
| 12 | 1.2418 |
| 13 | .9455 |
| 14 | 1.3137 |
| 15 | .8329 |
| 16 | 1.1377 |
| 17 | 1.0396 |
| 18 | .9943 |

INSTRUCTIONS FOR THE USE OF THE GODART PULMOTEST AND PULMO ANALYSOR

1. Fill the absorbers: the larger ones with sodalime or baralyme (4-8 ss) and the small ones with anhydrous $CaCl_2$ (2-3 mm). At both ends of each absorber insert a small guaze pad and replace the neoprene caps.

2. Insert a large guaze pad in the bottom of the main absorber which is on the front panel of the Pulmotest. Fill the absorber with baralyme to an inch and a half of the top.

3. Connect the apparatus to the mains (A.C. only, 110-115 Volts, 60 cps).

4. Before each test check the absorbers, and replace if exhausted. The baralyme is exhausted when it turns color and the $CaCl_2$ when it begins to solidify.

5. Switch on the apparatus, and wait 60 minutes before testing.

6. The Selector disk of the Pulmo Analysor must always be on "Closed Circuit".

7. Connections:

Pulmotest "+" to "in" of Pulmo Analysor

Pulmotest "-" to "out" of Pulmo Analysor

(The connecting nipples of the Pulmotest are at the back, those of the Pulmo Analysor at the right side of the apparatus).

8. Helium admission is made with a "T" piece, which intersects the tube going from "-" to "out".

9. Dead space determination of the Pulmotest should be done before every major test on it. Detailed instructions for this are written up in the Instruction Manual, P. 6.

10. The water level in the spirometer jacket should be maintained midway between the two red marks on the spirometer water level guage. Distilled water only should be used.

11. The flowrate for the spirometer should be maintained at 75 litres per minute by the flowmeter valve on the right hand side of the flowmeter.

12. Gently press down the counterweight of the left spirometer bell. Adjust the pen to the second litre mark on the paper. This will indicate zero level. Open the two-way tap and fill the left spirometer bell with 3½ litres of room air.

13. Open the helium and slowly add about ½ a litre into the Pulmo Analysor. Wait until the helium registers on the face of the analysor, and then adjust helium and room air until exactly four litres of air and helium are in the Pulmotest and the helium concentration measures between 900 and 1000. Mark down the helium concentration when the indicator steadies. The tracing pen is now resting on the baseline, and it is on this line that the

end of every expiration should rest. If the respiratory tracing rises above the baseline there is too little oxygen going into the circuit and the oxygen stabilizer must be lowered to increase the $O_2$ flow. If the tracing drops, there is too much $O_2$ and the stabilizer must be raised.

14. Request the subject to put in the mouthpiece and apply the nose clip. Allow the subject to breathe room air for a few minutes, during which time, check that the mouthpiece and nose clip are correctly positioned.

15. Switch on the kymograph motor: speed 30 mm per minute. Regulate the level of the oxygen stabilizer and open the oxygen valve.

16. At the end of a normal expiration open the two-way tap completely. (Caution: if the subject is not started on the Pulmotest at exactly the end of a normal expiration, the tracing pen will descend lower than the baseline, indicating a further dilution of the helium concentration and an error in measurement of the residual volume. In this case, disconnect the subject immediately, turn off the kymograph and oxygen, allow the subject to breathe room air for approximately 10 minutes to clear out any helium which may have entered his lungs, and repeat steps 12 to 16).

17. When the helium concentration has remained constant for a minute (this will happen after about 5 minutes of testing), instruct the subject to breathe out all his

air and then take it all back in, so that his vital capacity is recorded on the tracing.

18. Mark the helium concentration and disconnect the subject.

19. Trun off the kymograph and the oxygen.

20. Raise and lower the left spirometer bell until all the helium has been blown out of the circuit.

CALCULATION OF RESIDUAL VOLUME

Expiratory Reserve Volume (ERV) - that measured from the baseline to the bottom of the tracing in mms., then converted to litres of air at BTPS.

Functional Residual Capacity (FRC) = (initial He concentration - final He concentration) X (circuit dead space + added volume of air) / final He concentration.

or $FRC = V(C-C_1)/C_1$

where $V = 5.37$ (dead space air for this study) + 4.0 (volume air added to circuit)

$= 9.37$ litres.

Residual Volume = FRC - ERV